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On the decay of Bi^{203}

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With 6 figures in the text

ABSTRACT

The level scheme of Pb^{203} has been studied in the decay of 12 h Bi^{203}. 20 transitions were found. The experiments included energy and intensity measurements on conversion lines in permanent magnet and double-focusing spectrometers, measurements of relative gamma intensities in a scintillation spectrometer, electron-gamma and gamma-gamma coincidence measurements using a 100-channel pulse-height analyzer. Positrons were discovered; from studies in an intermediate-image beta-spectrometer, and in a double-focusing spectrometer the positron emission was resolved in two components, 740 ± 50 keV and 1350 ± 50 keV. A decay scheme is suggested.

1. Introduction

The present work was started at the Nobel Institute of Physics in 1955. Some preliminary results were given by Stockendal *et al.* [1, 2] 1956 and 1957. During the course of the present investigation, Fritsch [3] reported a study of the same isotopic decay, consisting mainly of measurements in permanent magnet beta-spectrometers for photographic recording. He found 15 transitions, including 11 of the 20 transitions found in the present work.

2. Experimental procedures

The Bi^{203} samples were mostly produced by bombarding radiogenic lead (containing 88 % Pb^{206}) with protons in the synchro-cyclotron of the Gustaf Werner Institute for Nuclear Chemistry. In these bombardments different bismuth isotopes were produced. Because of their different half-lives it was generally easy to distinguish between transitions belonging to different decays. However, in the case of Bi^{203} and Bi^{204}, which have nearly the same half-life (ca. 12 h), it was not possible to make a discrimination by this method. The isotopic assignment was therefore made from a comparison between an activity produced as described above, and a Bi^{204} activity—without additional Bi^{203}—produced by bombarding Tl with 38 MeV alpha-particles in the cyclotron of the Nobel Institute (cf. our work on Bi^{204} [4]: Fig. 1). It was also possible to distinguish between Bi^{203} and Bi^{204} transitions by using different proton bombarding energies in the irradiations of lead. An increase of the bombarding energy from 30 to 60 MeV was found to increase the ratio between the produced amounts of Bi^{203} and Bi^{204} by a factor 2. A further check of the isotopic assignment was in some cases made with electromagnetically separated samples.

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The separation of the active bismuth from the target materials and the preparation of sources is described elsewhere [1, 4, 5, 6].

The following instruments were used for the measurements:

(1) a permanent magnet beta-spectrometer for photographic recording [7] for energy determination of internal conversion lines;

(2) a double-focusing beta-spectrometer [8] for energy and intensity measurements as well as for the investigation of positrons;

(3) an intermediate-image beta-spectrometer [9] for studies of electron and positron spectra as well as for coincidence measurements;

(4) a single-channel scintillation spectrometer [10] with automatic recording for measurements of relative gamma intensities;

(5) a coincidence apparatus [11] in connection with a 100-channel pulse-height analyzer [12] and a beta spectrometer (see (3), above).

3. Internal conversion line measurements

Table 1 includes the energies and relative intensities of the conversion lines which were found in the decay of Bi^{203}. The assignment of those weak transitions for which only one line—assumed to be a K line—was found, is of course less definite. The

Table 1. Gamma transitions and internal conversion lines in the decay of Bi^{203}.

Transition energy (keV)	Conversion lines observed	K-line intensity (K 825.2 = 100)	Conversion ratios
60.3	L_{I}		
126.3	L_{II}, L_{III}, M, (no L_{I})	33 (ΣL)	$(L_{I}+L_{II})/L_{III}=1.5\pm0.6$
186.5	K, L_{I}, M, N, (no L_{III})	67	$K/L=5\pm1.5$
263.6	K, L_{I}, M, (no L_{III})	75	$K/L=5\pm1.5$
381.4	K, L_{I}	4.5	$K/L=5\pm1.5$
626.3	K	0.9	
722.4	K, L_{I}	1.2	$K/L=3.3\pm1.0$
758.3	K	$\approx 1^{a}$	
819.7	K, L_{I}	8.3	$K/L=4.5\pm1.5$
825.2	K, L_{I}, M_{II}	100	$K/L=3.4\pm0.6$
846.7	K, L_{I}	2.2	
932.0	K	0.8	
1033.6	K, L_{I}	3.1	$K/L=5\pm1$
1184.2	K	0.24	
1255.8	K	0.24	
1510.1	K	0.17	
1523.1	K	0.52	
1536.9	K, L_{I}	1.2	$K/L=6\pm1.5$
1846	K	0.25	
1896	K	0.36	

[a] Visual estimate from photographic film.

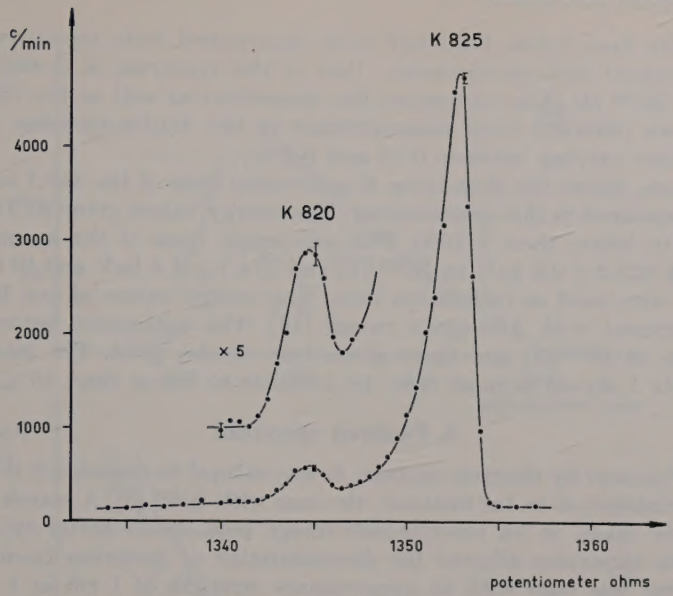

Fig. 1. K-conversion lines of the 819.7 and 825.2 keV transitions in Bi^{203} measured in the double-focusing spectrometer at 0.15 % resolution. The spectrum is corrected for decay.

Table 2. Multipolarities and intensities of transitions in the decay of Bi^{203}.

Transition energy (keV)	Gamma intensity for different multipolarities, calculated from K- (or L-) line intensity					Measured relative gamma intensity[a]	Probable multipolarity assignment (based on data from Tables 1 and 2)	Total transition intensity adopted from K- (or L-) line intensity
	$E1$	$E2$	$M1$	$M2$	$M4$			
60.3							$M1$	
126.3	890	21	49	4		80	$E2$	70
186.5	890	350	52	11			$M1$	130
263.6	2300	850	150	41		150	$M1$	240
381.4	320	120	25	8		< 130		
626.3	180	68	19	7				
722.4	320	120	35	14			$E2$	120
758.3	≈300	≈100	≈30	≈10				
819.7	2700	1100	330	140		1100	$M1\ (+E2)$[b]	⩾340
825.2					450		$M4$	590
846.7	780	300	97	40			$M1\ (+E2)$[c]	⩾100
932.0	330	130	45	19		< 200		
1033.6	1600	620	230	99		200	$M1$	230
1184.2	150	62	25	11				
1255.8	170	68	29	13				
1510.1	170	67	33	14		400		
1523.1	510	210	100	44				
1536.9	1200	490	240	105				
1846	340	140	80	35		450		
1896	500	220	130	53				

[a] The values were obtained from scintillation spectrum and should be considered as rough estimates. Because of the weakness of the electromagnetically separated sample this had to be placed near the crystal. For this reason the intensity values in column 3 may have been somewhat influenced by sum-up effects.

[b] An $E2$ admixture in this transition may explain the large ratio between the photo peaks at about 800 and 1000 keV in the γ-γ coincidence spectrum shown in Fig. 5.

[c] Cascade relations discussed in Subsection 8.c suggest that the transition intensity of the 846.7 keV transition is about 200, indicating an $E2$ admixture.

energies of the lines below 1100 keV were determined from measurements in the permanent magnet beta-spectrometer. Part of this spectrum is shown in Fig. 1 of our work on Bi^{204} [4]. The conversion line intensities as well as the energies above 1100 keV were obtained from measurements in the double-focusing spectrometer with resolutions varying between 0.15 and 0.5 %.

Fig. 1, above, shows the close-lying K-conversion lines of the 819.7 and 825.2 keV transitions measured in this spectrometer. The energy values given in Table 1 should be accurate to better than 1:1000. The conversion lines of the accurately known transitions of 825.2 ± 0.5 keV in Bi^{203} [1] and 374.7 ± 0.4 keV and 911.7 ± 0.3 keV in Bi^{204} [13] were used as calibration lines. The energy values of our Bi^{206} lines are in good agreement with Alburger's values [14]. The agreement between Fritsch's energy values of Bi^{203} [3] and those given here is also good. The intensity values given in Table 1 should in most cases be accurate to better than 15 %.

4. Positron spectrum

Since Bi^{203} decays by electron capture, it was natural to examine if it also decayed by positron emission as is, for instance, the case with Bi^{205} [5]. A search for positrons was therefore made in an intermediate-image beta-spectrometer [9]. The helical baffles in this apparatus allowed the discrimination of positrons from electrons. A circular source was used with an approximate strength of 1 r/h at 1 cm distance. By taking five-minute counts at a number of current settings the positron spectrum was obtained. The spectrum was remeasured several times and was found to decay with a half-life of approximately 12 hours. It was therefore concluded that the majority of the spectrum belongs to Bi^{203} or Bi^{204}, or to both of them. From a comparison with the amount of positrons emitted from a bismuth sample (with *no* Bi^{203}) obtained from an alpha-bombardment on Tl, it was found that the contribution of Bi^{204} positrons to the 12 h positron emission from the investigated sample ($Bi^{203} + Bi^{204}$) was less than 10 %.

Because of the possibility that scattered electrons could disturb the true spectral distribution, the positron spectrum was remeasured in the double-focusing spectrometer. The number of counts due to scattered electrons is less with this instrument because of its large dimensions. Besides, the background due to gamma rays is considerably reduced because of the efficient shielding of the GM-counter. However, the statistical errors are somewhat larger because of the lower transmission. The positron spectrum measured in the double-focusing spectrometer is represented in Fig. 2, which also shows a Fermi analysis. From the Fermi plot a positron energy of

$$E_{\beta+} = 1350 \pm 50 \text{ keV}$$

was obtained. The deviation of the Fermi plot from the straight line at energies below 700 keV might be interpreted as a second component with an energy of

$$E'_{\beta+} = 740 \pm 50 \text{ keV}.$$

From Fig. 2 the intensities of the two components were found to be 67 % and 33 %, respectively.

The deviation below 400 keV might be due to positrons from Bi^{204} and from backscattered electrons. The positron spectrum might also be influenced by positrons due to internal pair-formation of the high-energy gamma rays. This contribution is, however, estimated to be less than 10 %.

The intensity of the positron emission was found to be $(1.4 \pm 0.4) \times 10^{-2}$ positrons per 825.2 keV transition.

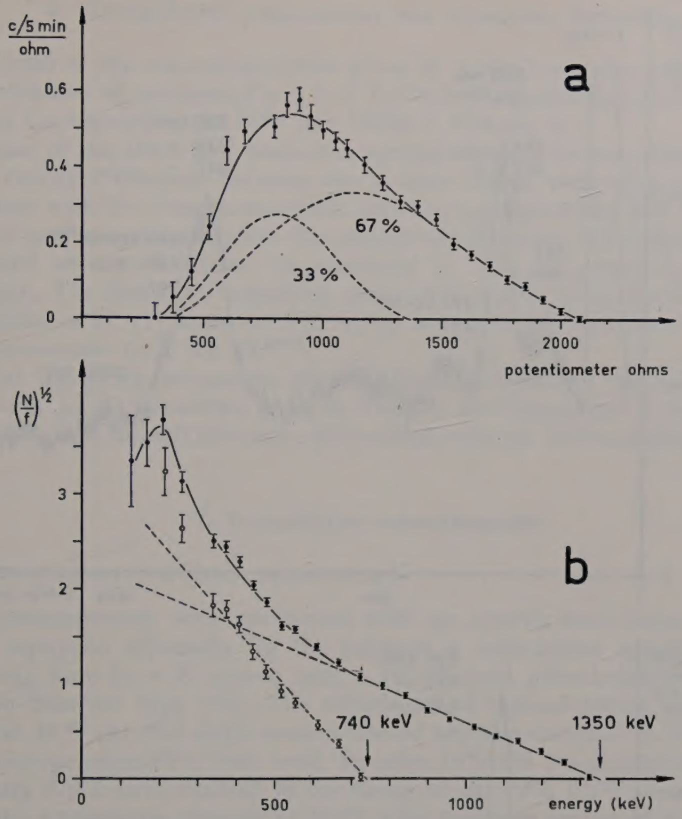

Fig. 2. (*a*) Positron spectrum measured in a double-focusing spectrometer. The background (30 % of the peak intensity) was subtracted. (*b*) Fermi plot of the positron spectrum shown in *a*. Allowed shape was assumed. Screening corrections were made. The errors shown are standard deviations.

5. Scintillation spectra

Scintillation spectra were measured with a $1\frac{3}{4}'' \times 2''$ NaI(Tl) crystal and a single-channel analyzer with a constant relative channel-width of 2 % [10]. Fig. 3 shows an automatic recording of the spectrum obtained with an electromagnetically isotope-separated sample of Bi^{203}. It is not excluded, however, that the sample also contained a small amount of Bi^{204}. By use of the known efficiency values for the crystal the relative gamma intensities, given in Table 2 column 3, could be estimated. The values are useful for suggestion of multipolarities to some of the transitions.

Spectra were also measured outside and inside a hollow crystal ($1\frac{3}{4}'' \times 2''$ Harshaw NaI(Tl)). In the latter spectrum, a clear sum-up peak was found at about 2.9 MeV and, in addition, a smaller peak at about 2.6 MeV (Compton?). This result will be discussed in Section 8.

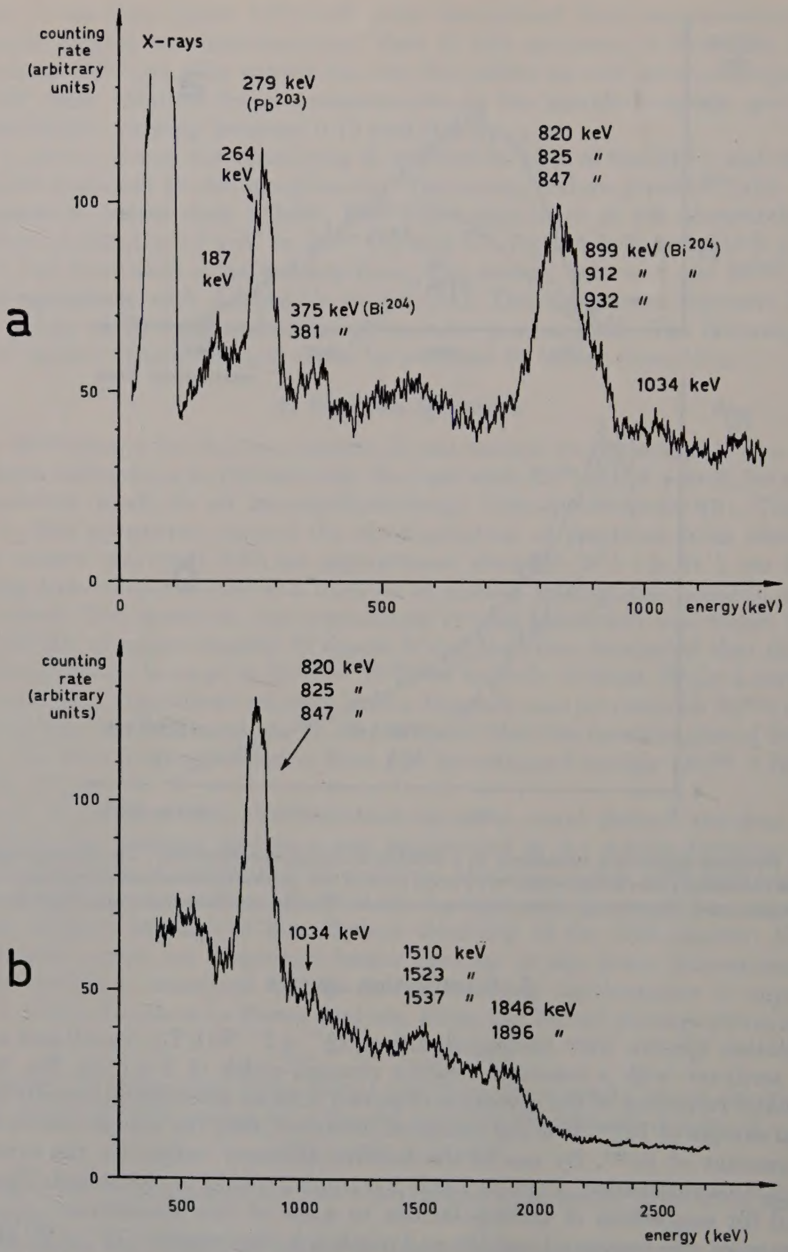

Fig. 3. (*a*) Low-energy region and (*b*) high-energy region of scintillation spectrum measured with a single-channel pulse-height analyzer with automatic recording and a constant relative channel-width of 2 %. The Bi^{203} sample was obtained from an electromagnetic isotope separation. It is not excluded, however, that the sample also contained a small amount of Bi^{204}.

6. Multipolarity assignments and transition intensities

On the basis of the conversion ratios given in Table 1 and the measured relative gamma intensities (cf. columns 2 and 3 of Table 2) multipolarities could be suggested for some of the transitions in Bi^{203} (see Table 2, column 4).

In the case of the 126.3 keV transition special information was obtained from the measured energy difference between the L lines. These were thus assigned as L_{II} and L_{III} lines, with the consequence that only the multipolarities $E2$, $E3$, $E4$ and $E5$ could come into consideration for this transition. However, all assignments, except for $E2$, could be excluded from the measured $(L_I + L_{II})/L_{III}$ ratio or from half-life consideration. The 825.2 keV transition was earlier shown to have multipolarity $M4$ by Stockendal *et al.* [1] from its K/L ratio, K-conversion coefficient and half-life, from measurements on 6 sec Pb^{203m}.

The total transition intensities given in Table 2, column 5, were calculated from the relative K (or L) intensities given in Table 1, the theoretical K-conversion coefficients by Sliv and Band [15] and the theoretical values of K/L according to Rose [16].

7. Coincidence measurements

(a) Electron-gamma coincidence measurements

These measurements were performed with an intermediate-image beta-spectrometer [9] equipped especially for the purpose, a coincidence apparatus [11] with the resolving time $2\tau = 30$ mμsec, and a 100-channel pulse-height analyzer of the Hutchinson–Scarrott type [12]. The techniques of measurements are described in our work on Bi^{204} [4]. For some measurements samples enriched in Bi^{203} by electromagnetic isotope separation were used. In order to avoid the disturbing gamma rays (of especially 279.2 keV) emitted in the decay of the 52 h Pb^{203} ground state, fresh sources with a minimum amount of Pb^{203} were prepared by use of an ion exchange column [1] immediately before the measurements.

For intensity reasons, and on account of the relatively poor resolution (ca. 3 %) in the spectrometer, the coincidence measurements were limited to the cases in which the following lines were focused in the beta channel: L 126.3, K 186.5, K 263.6 and K 819.7 + K 825.2 + K 846.7.

Fig. 4 shows spectra in coincidence with L 126.3, K 186.5 and K 263.6, respectively. They are, as can be seen, very similar, with photo peaks appearing at the approximate energies of 800 and 1500 keV. The 800 keV peaks should be due to one or both of the 819.7 and 846.7 keV gamma rays. It is excluded, however, that the 825.2 keV gamma ray should be observed in the coincidence spectra, since it is emitted directly to the ground state of Pb^{203} from an isomeric state with about 6 sec half-life [1]. The photo peaks at about 1500 keV could arise from one or several of the 1510.1, 1523.1 and 1536.9 keV gamma rays. The tails at the high-energy sides of the 1500 keV photo peaks might be due to the Compton distribution of some gamma rays of higher energies (1846 and 1896?). The corresponding photo peaks may not be visible because of the weakness of the gamma rays and the lower crystal efficiency at higher energies.

The low-energy regions of the above-mentioned spectra were investigated in separate measurements. Also these parts of the three spectra appeared to have about the same shape, characterized by a continuous increase of the coincidence rate towards lower energies. Although no pronounced photo peak was visible this result might

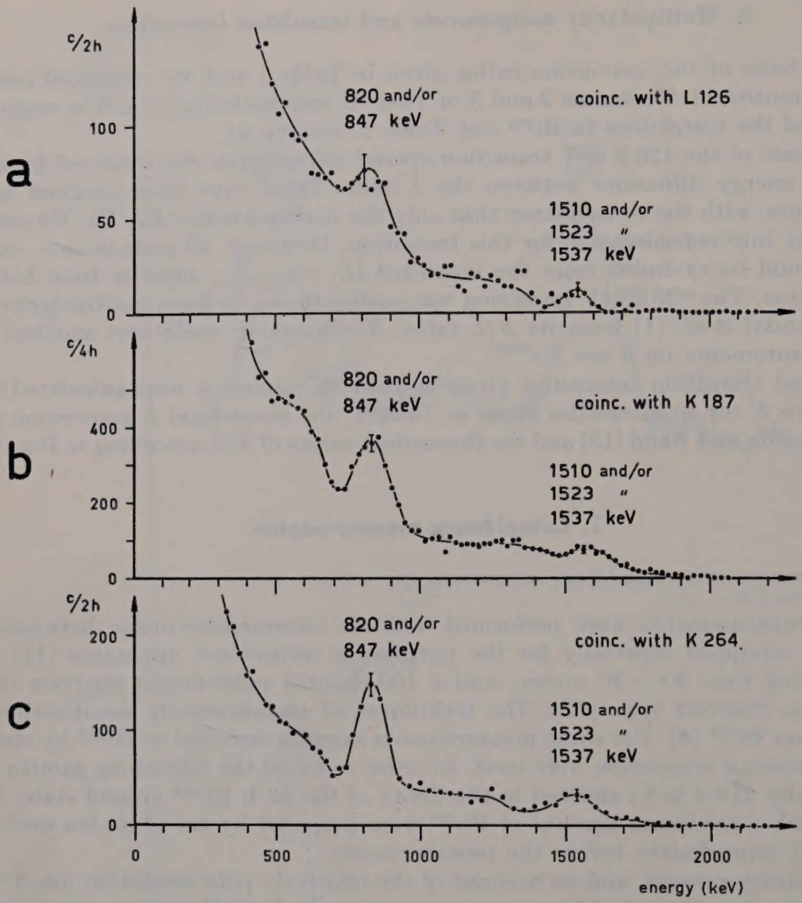

Fig. 4. Coincidence spectra measured by use of a 100-channel pulse-height analyzer and with (*a*) *L* 126.3, (*b*) *K* 186.5 and (*c*) *K* 263.6 focused in the beta channel (cf. the singles spectrum in Fig. 3). Absorbers of 1 mm Cd and 2.5 mm Pb were in *a* inserted between the source and the gamma detector, whereas in *b* and *c* only a Cd-absorber was used. As the resolving time of the coincidence apparatus is $2\tau = 30$ mμsec, the chance-coincidence rate was negligible (total rate ≈ 1 c/h).

indicate that low-energy gamma rays are in coincidence with the 126.3, 186.5 and 263.6 keV transitions. However, when the measurements were repeated with Pb-absorbers introduced between the source and the crystal, the coincidence rates did not change considerably. It may therefore be concluded that the majority of the low-energy pulses arose from the Compton distribution from gamma rays of higher energies.

In the coincidence measurements with the *K* 819.7 + *K* 825.2 + *K* 846.7 conversion lines focused in the beta spectrometer, the conditions were rather unfavourable because the strong *K* 825.2 keV line does not contribute to the true coincidence rate but only to the number of random coincidences. It was found that the 819.7 and/or 846.7 keV transitions are in coincidence with transitions of about 260 and 1500 keV, and possibly also with transitions of about 180 and 1800 keV.

The results of the electron-gamma coincidence measurements are given in Table 3*a*.

Table 3. Coincidences in the decay of Bi^{203}.

a. Electron-gamma coincidences

Conversion lines focused in electron channel	Gamma rays found in coincidence spectrum (energy in keV)
L 126.3	819.7 and/or 846.7 1510.1 and/or 1523.1 and/or 1536.9 1846 and/or 1896?
K 186.5	819.7 and/or 846.7 1510.1 and/or 1523.1 and/or 1536.9 1846 and/or 1896?
K 263.6	819.7 and/or 846.7 1510.1 and/or 1523.1 and/or 1536.9 1846 and/or 1896?
K 819.7 + *K* 846.7	186.5? 263.6 1510.1 and/or 1523.1 and/or 1536.9 1846 and/or 1896?

b. Gamma-gamma coincidences

Gamma ray studied in single channel (energy in keV)	Gamma rays found in coincidence spectrum (energy in keV)
1846 + 1896	186.5? 263.6? 819.7 and/or 846.7 1033.6

(*b*) *Gamma-gamma coincidence measurements*

By replacing the beta channel in the apparatus used above with a gamma channel, coincidences with the high-energy gamma rays could be studied. The discriminator in the single channel was set to accept pulses corresponding to gamma energies above 1800 keV. A typical coincidence spectrum obtained with the 100-channel pulse-height analyzer is shown in Fig. 5. The photo peaks at about 800 and 1000 keV should be due to the 819.7 and/or 846.7 keV gamma rays and to the 1033.6 keV gamma ray, respectively. It seems more difficult, however, to draw any definite conclusions from the photo peak of about 200 keV. Although it may be tempting to interpret this peak as composed by the photo peaks of the 186.5 and 263.6 keV gamma rays, it is not excluded that at least part of the photo peak is due to back-scattered (180°) gamma rays from Compton processes in the single-channel crystal.

(*c*) *Coincidences with positrons*

An attempt was also made to measure coincidences with positrons. In order to be able to use as strong a source as possible without overloading the electronics, a 7 mm Pb-absorber was placed between the source and the gamma detector. The magnet

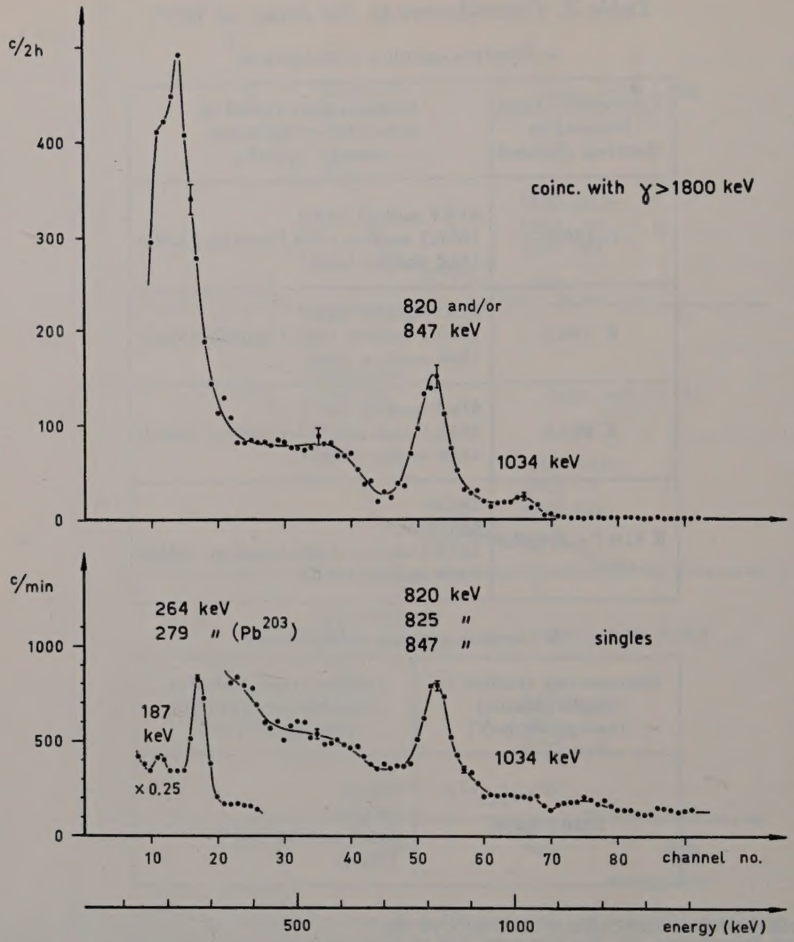

Fig. 5. Spectrum measured with a 100-channel pulse-height analyzer in gamma-gamma coincidence experiments. The discriminator in the single channel was set to accept pulses corresponding to gamma energies above 1800 keV (cf. the spectrum in Fig. 3).

field and the slits in the beta spectrometer were chosen such as to give optimum positron counting rate (180 c/min). The spectrum obtained after a 13 hour measurement shows indications to peaks around 600 keV and 800 keV. Because of the poor statistics, however, it is not possible to draw any definite conclusions from this measurement.

8. Construction of the decay scheme

(*a*) *The isomer* Pb^{203m}

Of significant interest for the construction of the decay scheme of Bi^{203} is the information about the isomer Pb^{203m}. It was produced by Stockendal *et al.* [1] by milking from a Bi^{203} activity and was found to decay by an $M4$ transition of energy 825.2 keV.

The transition was suggested to take place from an $i_{13/2}$ state directly to the Pb^{203} ground state assumed to be $f_{5/2}$. The half-life of the isomeric state was found to be 6.5 ± 0.5 sec. It was recently remeasured by Åström [17] who reports a value of 6.09 ± 0.10 sec.

(b) *Estimate of the total decay energy*

1. Since positrons were found in the decay of Bi^{203}, it is possible to draw some conclusions about the total decay energy. From the measured values of the positron intensity and the maximum positron energy (see Section 4) one finds by use of Moszkowski's nomogram [18] a log ft value of 7–8, indicating that the positron emission is accompanied by a change in angular momentum of 0 or 1 unit. As the spin value of Bi^{203} was recently found by Lindgren [19] to be 9/2 (atomic beam resonance method), it is not probable that positron emission takes place to the $5/2-$ ground state of Pb^{203} but rather to an excited state with spin value 7/2, 9/2 or 11/2. Thus, because the maximum positron energy was found to be 1350 ± 50 keV, a lower limit of the total decay energy can be set at about 2.4 MeV.

2. Further information about the decay energy can be found from the results obtained with the hollow crystal. As pointed out in Section 5, a clear sum-up peak of about 2.9 MeV was found in the scintillation spectrum taken with the source inside the crystal. It is therefore concluded that the total decay energy exceeds this value. Furthermore, it is reasonable to assume that the total decay energy is not very much higher than 3 MeV.

3. An estimate of the total decay energy of Bi^{203} can also be made by use of data from the decays of Bi^{205} [5] and Bi^{207} [20]. The energy difference $h_{9/2\,(\mathrm{Bi})} \rightarrow f_{5/2\,(\mathrm{Pb})}$ has in these decays values of 2.65 and 1.83 MeV, respectively. Under the rough assumption that this energy difference varies linearly with neutron number a value of about 3.5 MeV is extrapolated for the total decay energy of Bi^{203}. About the same value is also obtained from the total decay energies 2.65 MeV (Bi^{205}) and 2.40 MeV (Bi^{207}) by extrapolation in an energy—neutron number diagram using the same slope as is valid for other isotopes in this region (Pb→Tl, Tl→Hg, Hg→Au).

(c) *Energies of levels; assignment of spins and parities*

1. Because of the accuracy of the energy measurements it may be justified to start the construction of the decay scheme on the basis of *energy relations*. By addition of any two gamma energies given in Table 1, the sum obtained is in two cases, within the experimental errors, equal to the energy of a third gamma ray, namely:

$$\begin{aligned} 60.3 + 126.3 &= 186.6 \text{ keV}, \qquad E_\gamma = 186.5 \text{ keV}; \\ 186.5 + 846.7 &= 1033.2 \text{ keV}, \qquad E_\gamma = 1033.6 \text{ keV}. \end{aligned}$$

Thus these relations suggest that the 846.7 keV gamma ray is emitted in cascade with the 186.5 keV gamma ray as well as with the gamma rays of 60.3 and 126.3 keV. As the low-energy transitions (of 126.3 and 186.5 keV) are relatively strong (cf. Tables 1 and 2), it seems improbable that these transitions should take place from excited states in the high energy region where strong competition with transitions of higher energy is expected. As an example it may be mentioned that, according to the theory of Weisskopf [21], the gamma transition probability for an $M1$ transition of 800 keV is of the order of 10^6 times larger than for an $E2$ transition of 126 keV. It seems therefore more probable that these low-energy transitions should take place directly to

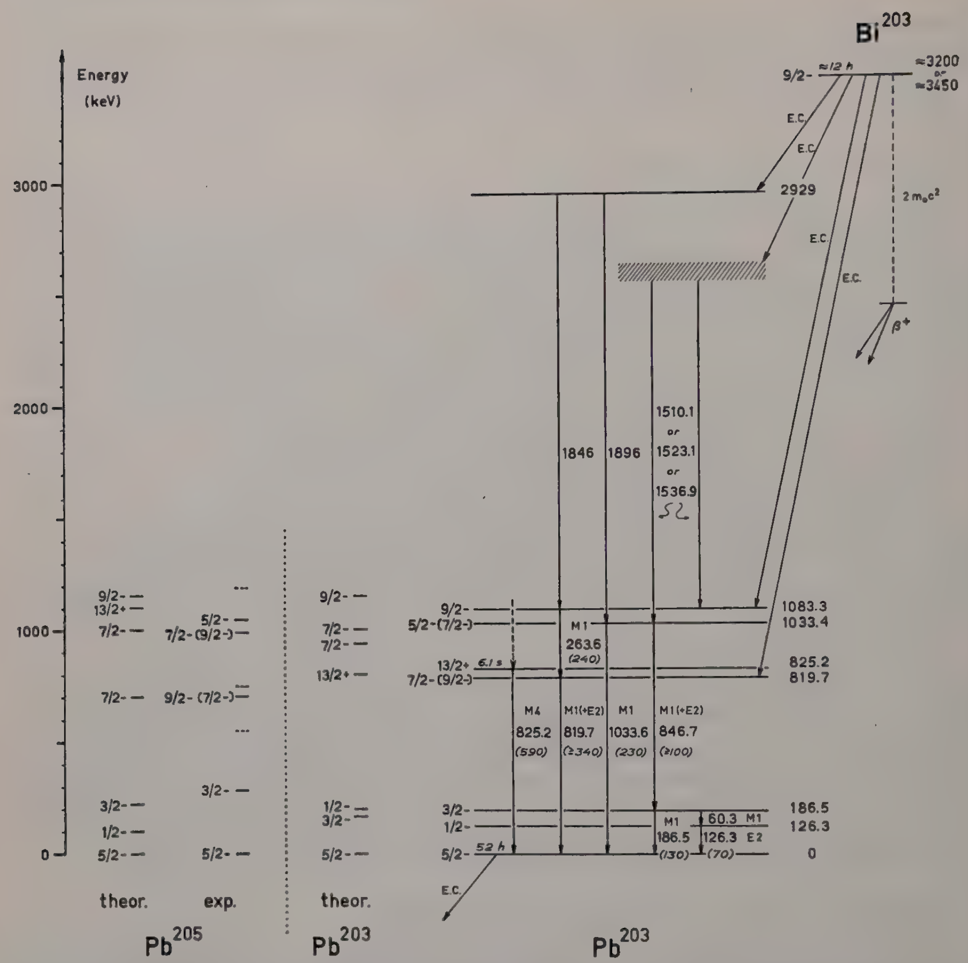

Fig. 6. Tentative decay scheme of Bi^{203} and for comparison the lowest states in Pb^{205} found by Schmorak *et al.* [5]. Below some of the energy values relative values of total transition intensities are given. Positrons of maximum energies 740 ± 50 and 1350 ± 50 keV were found. The latter component might populate the 819.7 keV or the 1083.3 keV state. The figure shows also the energies of some single-particle states (1/2 −, 3/2 −, 5/2 − and 13/2 +) and low-lying complex states (7/2 − and 9/2 −) in Pb^{203} and Pb^{205} calculated by Pryce [22]. These energy values should be considered as rough.

the ground state from excited states of 126.3 and 186.5 keV. If this is the case, the 846.7 and 1033.6 keV transitions are suggested to take place from an excited state of 1033.4 keV (mean value of 1033.2 and 1033.6 keV). The multipolarities of the 60.3, 126.3 and 186.5 keV transitions suggest spin and parity 1/2 − and 3/2 − for the 126.3 and 186.5 keV states, respectively. Since the 1033.6 keV transition is of multipolarity $M1$, the 1033.4 keV state may have spin and parity 3/2 −, 5/2 − or 7/2 −. However, the 3/2 − assignment might be excluded, since no transition is observed to the 126.3 keV 1/2 −state. The assignment 7/2 −, which requires the 846.7

keV transition to be of multipolarity $E2$, seems also less probable from a comparison between the intensities of the 1033.6 and 846.7 keV transitions.

2. As the additional information obtained from the energy values is less decisive, the further building up of the decay scheme is based mainly on the *coincidence results*, the *multipolarity assignments* and the *transition intensities*. To start with, the 263.6 keV transition is found to be in coincidence with the 819.7 keV transition and/or the 846.7 keV transition, but not in coincidence with the 1033.6 keV transition (see Table 3*a* and Fig. 4). Since the latter two transitions are both assumed to take place from the excited state of 1033.4 keV (see Fig. 6), it is probable that the 263.6 and 819.7 keV gamma rays belong to the same cascade. The suggestion shown in Fig. 6 seems to be the most plausible for the following reasons. Firstly, the 263.6 keV $M1$ transition is likely to take place from a relatively low level (for the same reasons as are given above for the 126.3 and 186.5 keV transitions). However, it does not seem probable that the transition goes directly to the ground state from a state of 263.6 keV, since a transition to such a state from the 1033.4 keV state would have been observed in the experiments. Secondly, it is probable that also the 819.7 keV transition takes place from a relatively low state, as no coincidences were observed with the 846.7 or 1033.6 keV transitions (see Table 3*a*). Finally, the suggestion in Fig. 6 is in agreement with the fact that no coincidences were observed between the 263.6 keV transition and any of the 126.3 or 186.5 keV transitions. Since the 819.7 keV transition is probably mainly of multipolarity $M1$ ($E2$ less probable), it is suggested that the state of 819.7 keV has spin and parity 7/2 −. However, a 9/2 − assignment cannot be excluded. The assignments 3/2 − and 5/2 − are not consistent with the non-observability of transitions to the low-lying states of 1/2 − and 3/2 −. The most plausible spin and parity assignment of the 1083.3 keV state seems to be 9/2 −, since the 263.6 keV transition is of multipolarity $M1$ and since no transitions are observed to the 825.2 keV 13/2 + state or to the 5/2 − ground state.

The result of the gamma-gamma coincidence experiment (see Table 3*b*) requires a direct or indirect feeding to the 1033.4 keV level by any of the 1846 or 1896 keV transitions. Furthermore, the high intensity ratio between the photo peaks at about 800 and 1000 keV in the coincidence spectrum shown in Fig. 5, may be explained only if also the 819.7 keV level is directly or indirectly fed by one of the 1846 or 1896 keV transitions. The suggestion in Fig. 6 is supported by the fact that the energies in each cascade have the same sum, 2929 keV, indicating a level at this energy.

The 186.5 and 1083.3 keV levels should be directly or indirectly fed by transitions of about 1500 keV, since photo peaks of this energy were found in the gamma spectra in coincidence with the 126.3, 186.5 and 263.6 keV transitions, and also with one or both of the 819.7 and 846.7 keV transitions. The decay scheme of Fig. 6 shows possible positions for at least two of these 1.5 MeV transitions.

Since no definite multipolarity assignments are known for the high-energy transitions, the spins and parities of the higher states cannot be decided. However, it is reasonable to assume that they have spin values 7/2, 9/2 or 11/2, as they are probably directly fed from the 9/2 − ground state of Bi^{203}.

3. It cannot be unambiguously decided which levels are fed by *positron* emission. As was pointed out in Subsection 8.b.1, however, the log *ft* value indicates that the positron emission with 1350 keV maximum energy takes place to a state with spin value 7/2, 9/2 or 11/2. Furthermore, since the total decay energy of Bi^{203} is expected to be about 3.5 MeV (see Subsection 8.b), it seems plausible to assume that the positrons feed either the 1083.3 keV state or the 819.7 keV state. These suggestions would give rise to a decay energy of about 3450 or 3200 keV, respectively. In addition, both possibilities are in agreement with the indication that positrons are in coincidence with a transition of about 800 keV (see Subsection 7.c).

4. The suggested decay scheme of Fig. 6, including levels at about 2.6 and 2.9 MeV, is finally also supported by the fact that sum-up peaks of about 2.6 and 2.9 MeV were found in the experiment with a *hollow* crystal (see Section 5 and Subsection 8.b.2).

5. From the present investigation no conclusions can be made regarding the feeding to the *isomeric* 13/2+ *state*, since no simple energy relations were found containing the 825.2 keV gamma energy. It might, however, be fed from higher levels via transitions not yet included in the decay scheme.

6. It may be interesting to compare the suggested level scheme of Pb^{203} with that given by Schmorak *et al.* [5] for Pb^{205}, the next even-odd neighbour isotope. The spins, parities and positions of the lowest states of Pb^{205} are therefore included in Fig. 6. As can be seen, the two level schemes are rather similar. Regarding the failure to observe a metastable $i_{13/2}$ state in Pb^{205}, see refs. 1 and 5.

Fig. 6 shows also the energies of some single-particle states (1/2−, 3/2−, 5/2− and 13/2+) and low-lying complex states (7/2− and 9/2−) in Pb^{203} and Pb^{205}, calculated by Pryce [22]. It must be kept in mind that the calculations are rough. Nevertheless the agreement between theoretical and experimental levels is reasonably good.

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